Solution Brief

Energy

Modernizing the Power Grid with Software-Defined Infrastructure

Intel helps the energy industry transform and enable an efficient, resilient, secure smart grid through membership and commitment to the Virtual Protection Automation and Control (vPAC) Alliance as well as creation of technologies to drive it, including Intel® Xeon® 6 processors with up to 144 high-efficiency cores.

With the growing prevalence of renewable sources such as solar and wind farms, energy suppliers are reaching an inflection point. Longstanding assumptions based on centralized nuclear and fossil-fuel generation with one-direction transmission to consumers are giving way to bidirectional power transmission to and from distributed sites. New loads are being added to the grid as well, including massive growth in data-processing infrastructure and the shift from petro-powered transportation to electric vehicles. These changes lie at the heart of a redefined state of opportunity for the industry.

Cost advantages can be realized by directing power from renewables that are closer to the loads they serve, depending on shifts in supply and demand, with the capacities of renewable sources varying dramatically over time by their nature. Customers may also generate electricity that they feed back into the grid, and third parties may shift back and forth dynamically in their roles as producers and consumers, the basis of emerging so-called "prosumer" relationships.

New business models must be devised to take advantage of these trends, and they require the grid to become smarter. Increased digitization must collect sensor data from across distribution and supply networks, analyzing it at the edge to generate insights that drive low-latency management and control such as automatic isolation and re-routing in the event of equipment failure, optimized dynamic shifting among energy sources and embracing bidirectional prosumer relationships.

Intel's commitment to this transition is demonstrated by its status as a founding member of vPAC, an industry coalition dedicated to modernizing energy grids globally. The vPAC vision includes developing virtualized versions of substation PAC equipment using a standards-based, software-defined approach to make global power grids more adaptive, resilient, secure and intelligent. Platform innovation including Intel® Xeon® 6 processors helps advance that vision, building data-driven grids for better visibility, insight and decision making.

Challenges behind evolution of the data-driven grid

Modernizing utility substations is a central requirement for enabling the smart grid. Today's substations have been in service for more than 40 years on average,[1] held over from the analog era. They depend on a patchwork of siloed command and control systems that severely limit visibility across systems as well as the potential for automation. Typical PAC systems deployed today are based on thousands of fixed-function devices such as sensors, relays and controllers, all based on proprietary hardware and software.

The sprawl of bespoke appliances at today's substations is capital-intensive, inefficient and inflexible. It locks utilities into fixed architectures that block evolution toward the smart grid. In addition to its dependence on dedicated physical devices, this operational technology (OT) within the substation environment is also isolated from collocated information technology (IT) components for functions such as networking and security. Together, these factors complicate and add to the cost of monitoring, maintenance and upgrades, requiring truck rolls even for simple, routine tasks.

Decentralized legacy infrastructure where OT and IT are siloed from each other dramatically reduces visibility across the environment as well. Isolated systems that require manual collection of operational monitoring data restrict manageability of the grid as a whole, with a lack of real-time data for analysis and control. This gap in insight about load supply, demand and other factors can make it impossible to dynamically optimize the grid for higher efficiency and profitability. Capabilities such as feeder load balancing, feeder storage management and demand/generation flexibility are limited or impossible in these scenarios.

Aging legacy control mechanisms with limited manageability represent a large, vulnerable security perimeter that is not compatible with modern distributed security practices. Among today's geopolitical pressures, critical infrastructure has become the top target for cyberattacks worldwide, perpetrated largely by malevolent actors with political motivations. These range from nation states to criminal organizations and terrorist groups.[2] The U.S. Department of Energy identified 95 human-caused incidents targeting the electricity sector in the first half of 2023 — more than any previous half-year since it started tracking attacks in 2020.[3]

At the same time, customer usage patterns are shifting in response to the climate. In the Pacific Northwest region of the U.S., for example, higher summer temperatures have led to an explosion of demand for air conditioning. The percentage of rental housing units in Seattle with air conditioning has nearly doubled in the past six years.[4] Electric vehicle charging stations are becoming fixtures in our public spaces. Massive data centers are being built out constantly — including in the world's hottest places — to serve our limitless need for computing resources.

These trends may all be expected to continue and intensify. At the same time, they are accompanied by opportunity. Smart grids will help reduce costs and harden security postures, and as capacity demands swell, they will enable new business models to realize the full benefit of shifts that include the rise of renewables, prosumers and two-way power transmission.

Software-defined infrastructure as a strategic imperative

The modernized smart grid will support future needs and business models by re-architecting substation application infrastructure. Virtualizing intelligent electronic devices (IEDs) enables a grid defined in software that responds dynamically to changing conditions.

The resulting environment embraces data-driven operations and maintenance functions that can dramatically reduce operating expenses by continually optimizing the grid. For those utility companies that have already virtualized their control centers and other network sites, virtualization of substation edge servers helps enable a single, coherent operating environment that increases efficiency, agility and resiliency.

The need to re-imagine substation security

Historically, substation security has focused on legacy physical controls, such as fences and human monitoring. While cost-efficient and valuable, these approaches are limited and subject to error against physical attacks and intrusions, and they are ineffective against cyberattacks.

Utilities deploying technology measures to counter these threats are limited by the lack of integration among controller systems as well as the siloed nature of OT and IT. Increased digitalization in the smart web enables security software such as firewalls and intrusion detection systems to help protect every device in the environment. These tools will be made even more effective through AI enhancements and an overall view that enables holistic threat detection and response.

In addition to such attempts to deliberately interfere with power distribution, climate change has injected a growing degree of uncertainty into the landscape. Severe weather and flooding are on the rise, which may damage substation equipment, requiring triage of equipment and rerouting of power. Limited visibility and control in legacy environments limits the viability of centrally managing such response, potentially increasing costs and the lengths of service interruptions.

Virtualized IEDs (vIEDs) operate on standards-based commercial off-the-shelf servers, where they interoperate and share that hardware along with networking and security functions. This model can dramatically reduce both capital and operating expenses compared to traditional fixed-function devices, without vendor lock-in. Energy suppliers can choose among best-in-class operating and security software to optimize and protect their environments.

Broad-based transformation underlies the smart grid

The fundamental distributed computing requirements for the smart grid transition echo transformational changes over the past decade in other spheres. Enterprise computing pioneered the use of virtualization to decouple workloads from the hardware they run on, including containerized microservices that enable applications from multiple vendors to be instantiated anywhere in the environment.

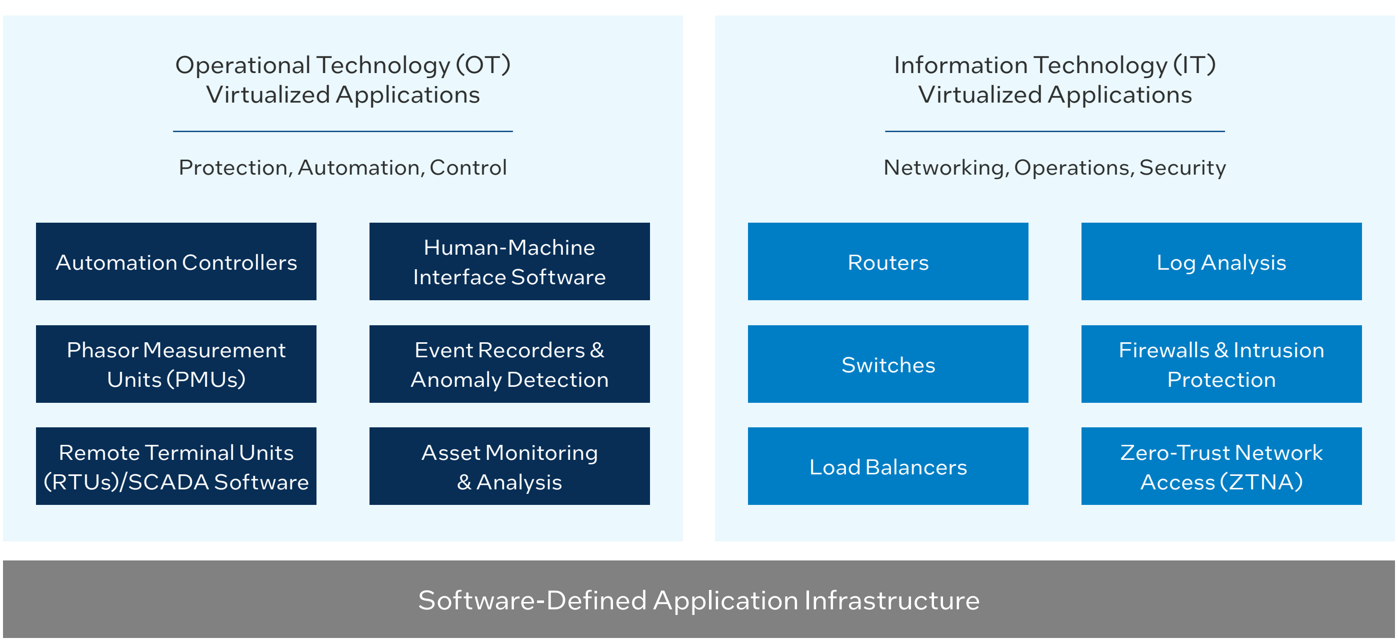
Edge computing consumes data close to where it is generated, allowing for low-latency usages including industrial safety applications and synchronous communications. Patterns of success in the telecommunications sector — including deterministic workloads that require exceedingly low latency and high reliability over distributed networks — are particularly noteworthy in setting the stage for evolution in the energy industry.

IT and OT are converged in this environment, with both delivered as microservices that are packaged with all their dependencies in containers that can execute on any general-purpose server. These small, modular software components are centrally orchestrated: created and destroyed whenever and wherever in the network they are needed. That centralization ensures that the software is always up to date to heighten functionality as well as security, and the dynamic nature of the deployment makes efficient use of server resources.

Applications can run on edge servers located at the substation site itself to enable minimal latency, including for real-time protection and control functions. They can also execute at central locations such as control centers or on public cloud instances. Those centralized modalities are appropriate for overarching management functions as well as for offline bulk tasks such as analytics or AI model training, which have the benefit of data from anywhere in the environment, helping realize the data's full value potential for the business.

In addition to these agility and flexibility advantages, software-defined application infrastructure is the basis for utilities to create and enforce robust security postures to protect their businesses as well as society at large. The container-based environment is explicitly built to implement open-standards security software from any vendor, alongside any other. Those diverse elements work together to protect both OT and IT elements distributed across the grid. That extensibility and interoperability make it possible to harden environment security. This includes the use of modern practices such as zero-trust network access (ZTNA), where every transaction is individually authenticated and authorized to optimize protection of data, facilities and services.

Converged OT and IT Virtual Functions for Energy Suppliers



CPU innovation for digital substations

Intel's commitment to the vPAC Alliance is predicated on enabling power service providers with technologies to drive the smart-grid vision forward. Standards-based servers are fundamental to replacing static, inefficient fixed-function approaches with dynamic, efficient ones for open interoperation in distributed networks.

Intel combines platform expertise with an unparalleled software and solutions ecosystem to guide its ongoing collaboration with the energy sector. To help ensure fidelity between technology development and the needs of energy suppliers on the ground, Intel follows the precept of "utility-guided innovation." This approach is based on early and ongoing work with global energy companies to learn what they need and refine the technology to provide it.

Intel Xeon 6 processors give energy suppliers unprecedented ability to deploy high-performance parallel compute at scale with higher performance per watt than previous generations.[5] High core density enables dedicated compute resources to be assigned among large numbers of individual vIEDs and IT functions for high throughput and resiliency, while built-in security capabilities help safeguard distributed and service-based architectures. Xeon 6 CPUs deliver advanced resources across a balanced platform:

- **Up to 144 Efficient-cores (E-cores) per socket**, in one- or two-socket configurations, are augmented with built-in accelerators[6] that enhance targeted workloads for high throughput at scale.
- **Eight DDR5 memory channels per CPU**, operating at up to 6400 MT/s, provide up to 15% higher bandwidth versus the previous generation to keep the massive execution resources supplied with data.
- **Up to 88 lanes of PCIe 5.0 per socket and Compute Express Link (CXL) 2.0** provide robust I/O to support workload acceleration and data growth for next-generation substation application architectures.

As AI becomes more central to security and networking functions, built-in AI acceleration based on Intel® Advanced Vector Extensions (Intel® AVX)[6] improves inference performance and offloads that functionality from the CPU cores, freeing resources for other work to improve scalability. The CPUs also help meet the real-time deterministic requirements of protection and control workloads with performance prioritization using Cache Allocation Technology (CAT) within the Intel® Resource Director Technology (Intel® RDT) framework.

To enable zero trust security frameworks in the face of the expanding attack surfaces associated with the smart grid's software-defined application infrastructure, the Xeon 6 platform provides network and network security capabilities from packet processing acceleration, cryptographic processing using instructions sets and Intel® QuickAssist Technology (Intel® QAT), to confidential computing based on Intel® Software Guard Extensions (Intel® SGX) and Intel® Trust Domain Extensions (Intel® TDX). These confidential computing technologies provide trusted execution environments that help protect the security workloads themselves as well as isolate sensitive data such as encryption keys while they are in use and protect them from exposure to unauthorized parties.

Ruggedized servers based on Intel Xeon 6 processors help ensure system reliability even in extreme substation conditions. Long-life availability[7] helps ensure that solutions can benefit from these enhancements for years, until customers are ready for the next hardware upgrade.

Conclusion

Together with the rest of the vPAC Alliance, Intel is enabling the power grid of the future, consolidating fixed-function OT and IT components onto open, virtualized, software-defined platforms. Intel Xeon 6 processors with E-cores advance the vision of data-driven grids with next-generation performance, efficiency and security. On these foundations, energy suppliers are poised to create future-focused infrastructure with the agility and efficiency to meet emerging requirements while securing a competitive advantage.

Enablement in the server ecosystem

Intel partners Lanner and Welotec are developing next-generation ruggedized servers for the utility market, conformant with IEC 61850-3 Class 2, to run protection, automation and control workloads.

"As we embark on the next phase of grid modernization to accelerate the adoption of renewable energy, Intel Xeon 6 with its 64 E-cores will be instrumental in driving efficiency and reliability, propelling us towards a smarter, greener future."

– Jos Zenner, Chief Technology Officer (CTO), Welotec GmbH

"Intel Xeon 6 leverages 64 E-cores for performance and efficiency to optimize power grid digitalization using Lanner's next-generation, IEC61850-3/IEEE1613 substation automation and control solutions."

– David Meng, Sr. Director, Strategy & Business Development, Lanner Electronics USA

Learn More:

https://www.intel.com/energy

[1] GE Vernova. "The Digital Substation Ups Its Game." https://www.gevernova.com/grid-solutions/press/gepress/digital-substation-ups-its-game.htm.

[2] Statista, March 26, 2024. "The Sectors Most Targeted by Cybercrime." https://www.statista.com/chart/31985/number-of-cyber-attacks-recorded-per-sector/.

[3] ASIS, February 1, 2024. "Girding the Grid." https://www.asisonline.org/security-management-magazine/monthly-issues/security-technology/archive/2024/february/girding-the-grid.

[4] Building Design + Construction, November 17, 2023. "Air conditioning amenity sees largest growth in Pacific Northwest region." https://www.bdcnetwork.com/air-conditioning-amenity-sees-largest-growth-pacific-northwest-region.

[5] For more complete information about performance and benchmark results, visit intel.com/PerformanceIndex.

[6] Availability of accelerators varies depending on SKU. Visit the Intel® Product Specifications page for additional product details.

[7] Intel does not commit or guarantee product availability or software support by way of road map guidance. Intel reserves the right to change road maps or discontinue products, software and software support services through standard EOL/PDN processes. Contact your Intel account rep for additional information.

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